

UDC 502.172.4:355.4.046.5:661.8.052.2

DOI: 10.31548/plant2.2024.67

Yulia Shaforost

PhD in Chemistry, Associate Professor
Bohdan Khmelnytsky National University of Cherkasy
18031, 81 Shevchenko Blvd., Cherkasy, Ukraine
<https://orcid.org/0000-0002-0002-2803>

Oleg Pogrebniak

PhD in Chemistry, Associate Professor
Bohdan Khmelnytsky National University of Cherkasy
18031, 81 Shevchenko Blvd., Cherkasy, Ukraine
<https://orcid.org/0009-0000-2289-0487>

Olena Lut

PhD in Chemistry, Associate Professor
Bohdan Khmelnytsky National University of Cherkasy
18031, 81 Shevchenko Blvd., Cherkasy, Ukraine
<https://orcid.org/0000-0002-0288-4255>

Valentina Litvin

PhD in Chemistry, Associate Professor
Bohdan Khmelnytsky National University of Cherkasy
18031, 81 Shevchenko Blvd., Cherkasy, Ukraine
<https://orcid.org/0000-0003-1236-6344>

Oleksandr Shevchenko

PhD in Chemistry, Associate Professor
Bohdan Khmelnytsky National University of Cherkasy
18031, 81 Shevchenko Blvd., Cherkasy, Ukraine
<https://orcid.org/0009-0007-5769-1884>

Chemical military-technogenic load on the soils of military training grounds

Abstract. Research on the military-technogenic burden on the natural environment as a result of international conflicts is relevant since military operations cause catastrophic consequences for the environment and natural resources, which can lead to irreversible disturbances in ecosystems. The study is devoted to the examination of the impact of military-technogenic loads on the soils of military training grounds. The paper considers methods of soil sampling and their analysis for the

Suggested Citation:

Shaforost, Yu., Pogrebniak, O., Lut, O., Litvin, V., & Shevchenko, O. (2024). Chemical military-technogenic load on the soils of military training grounds. *Plant and Soil Science*, 15(2), 67-79. doi: 10.31548/plant2.2024.67.

*Corresponding author



Copyright © The Author(s). This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (<https://creativecommons.org/licenses/by/4.0/>)

content of heavy metals and other chemical compounds and determines the impact of this load on the ecosystem and possible consequences for human health. The influence of military activity on the soil quality of military training grounds, in particular in the Cherkasy region, is analysed. The study includes the determination by X-ray fluorescence and atomic emission method of the content of various elements in the soil. The results showed a substantial iron content, which may be due to the use of explosives in military exercises. It is noted that despite the fact that exceeding the norms of maximum permissible content concentration, no heavy metals were recorded in the examined soils, and the maximum lead content approached the maximum permissible concentration, which requires further monitoring and control of this parameter. Ph determination showed a slightly acidic soil condition in combat exercise sites, which can affect plant fertility and growth. The content of nitrogen, phosphorus, potassium, and boron was assessed, and the results showed a lack of these nutrients for normal plant development. It is established that soil damage as a result of military operations can have a long-term negative impact and pose a threat to residents and territories. The results of the tests indicate a slight technogenic load at the sites of military exercises. The detected contamination of the examined samples is insubstantial, which indicates that the impact of military activities on the soil condition is limited. The results of the study will help to understand the possible health risks for people living near military training grounds and respond appropriately to protect their health

Keywords: chemical pollution; heavy metals; pollution monitoring; military exercises; environmental impacts

INTRODUCTION

An important task during the Russian-Ukrainian war is to localise the consequences of an environmental disaster as quickly as possible to minimise the damage caused by the Russian army to the environment and soil. The relevance of the study lies in the fact that the military-technogenic load on the soils of military training grounds has potentially severe consequences for the environment and human health. Armed conflicts and military operations can lead to substantial soil contamination with heavy metals, harmful chemicals and other dangerous compounds, which threatens environmental stability. The study on this issue will allow a better understanding of the scale of pollution and its possible consequences, which in the future can become the basis for developing effective measures to manage crisis situations and restore the environment after the end of a military conflict, quickly assess the amount of pollution, and develop ways to restore soils. Actions related to the storage, maintenance, testing, and even normal operation of military installations can lead to the spread of hazardous chemicals, fuels, lubricants, explosives, and other harmful compounds into the environment. This can cause soil and groundwater pollution,

which in turn threatens human health, flora and fauna, and can also have negative environmental consequences for natural ecosystems in the long term. Therefore, examining the impact of military operations on soils is important for understanding and managing the environmental impact of military activities. Russia's full-scale invasion of Ukraine has destroyed and continues to destroy the country's infrastructure.

Firing and detonating all types of ammunition leads to chemical contamination of the soil. Shelling often causes fires in the fields. As a result, according to the data obtained by A.V. Skalny *et al.* (2021), fertile soil layers burn out, they are dehydrated and "sterilised", and both pathogenic microorganisms and useful biota die. Nutrients are also lost. Its upper fertile layer, which has been formed for centuries, is being destroyed. In addition, many toxic compounds enter the soil. Rocket explosions produce carbon monoxide and carbon dioxide, water vapour, nitrogen oxides, formaldehyde, cyanide vapours, and a large amount of toxic organic substances. Many toxic compounds are also produced, such as sulfur and nitrogen oxides, which, when oxidised, cause acid rain. They can alter the pH of the soil and cause chemical burns to plants and

the respiratory mucosa of humans, birds, and mammals. Large amounts of mercury, zinc, cadmium, copper, nickel, lead, phosphorus, and barium accumulate in the places of shelling, the levels of which exceed the norm by dozens of times. According to the state environmental Inspectorate, as of October 1, 2022, losses caused by Russian troops to Ukraine's environment amounted to UAH 1.256 billion. Of this amount, losses to land resources amounted to UAH 407 billion, of which more than UAH 2 billion – due to soil pollution (McNutt & Hildebrand, 2022). It is hard to underestimate the importance of soil in an ecosystem. Military operations have a substantial impact on the natural state of the soil, as note by T. Stadler *et al.* (2022). The war in Ukraine and its extensive media coverage substantially increased professional and public attention to the burden on the environment in general and on soil pollution in particular, caused by military operations (Shukla *et al.*, 2023). Military exercises at training grounds are accompanied by an increase in the negative impact on the environment. Y.M. Krylova-Grek (2022) noted that the destruction of the ground also occurs during explosions of ammunition, the construction of trenches, dugouts, and other combat positions. This is usually observed at objects such as training grounds, in particular, tank training grounds and shooting ranges. Heavy technogenic loads caused by the movement of vehicles, mainly tracked vehicles, lead to soil erosion, siltation, or waterlogging, which exceeds the permissible limits and poses a threat to the environment. The soil of landfills is additionally contaminated with various metal waste, such as shell casings, sheathed parts of explosive devices, and even ammunition left unexploded. S. Yang *et al.* (2021) noted that these substances pose a substantial danger to human and nature life and health, as they can be potential sources of poisoning and pollution of water sources, soil, and air. Such materials can be stable for a long period of time and remain active even after the end of hostilities, so they must be removed and processed by specialised methods for destruction or safe storage to prevent possible negative consequences for ecosystems and human health.

Yu. Shaforost *et al.* (2022) established that the negative impact on the environment is not

limited to the formation of huge amounts of garbage and waste. It also includes emissions of hazardous materials such as asbestos, various industrial chemicals, and fuels that enter the soil, water sources and air, causing serious pollution and toxicity problems. As a result, a person is at risk of poisoning and other negative health effects, which can lead to serious diseases and even death. Such soil is degraded, the waterproof layer of bedrock is destroyed, soil fauna dies, and soil erosion occurs, which leads to global climate change. As a result, not only the air and soil can be polluted, but also groundwater. Since agricultural products are grown on this soil, and groundwater is used as drinking water, all these elements enter the food chain of living organisms, in particular, humans. A.J. Barker *et al.* (2021) argue that the problem is that military-technogenic loads on the soils of military landfills can lead to serious environmental pollution with toxic substances and heavy metals. Military actions cause destruction of natural resources, soil pollution, increased erosion and reduced soil fertility, which can affect agricultural production and threaten human health due to the migration of toxic substances to plants and water sources. Such contamination may have long-term impacts on the region's ecosystems and biodiversity. Understanding this problem is important for developing crisis management strategies and restoring environmental balance after the end of military conflicts.

The purpose of the study was to conduct a chemical assessment of the level of soil contamination at a military training ground in the Cherkasy region.

MATERIALS AND METHODS

For soil analysis, samples were taken on the territory of a military facility in one of the villages of the Cherkasy region. Sampling was conducted in the spring period (March 2023), after the snow melted. Soil samples were taken in various places: in the crater (the centre of the explosion), on the periphery of the explosion, places affected by mortar and artillery attacks, the use of small arms, and the neutralisation of ammunition. Test sites were selected to examine the most dangerous and technogenic-burdened areas. Preliminary soil samples were taken directly

from the combat training sites. Sampling was conducted in the morning on a clear day before the temperature rose. In the morning, when exposed to sunlight, the soil may be slightly drier, which makes sampling easier and prevents the humidity of the samples from increasing. In addition, the morning hours are usually a time of minimal activity and air movement, which avoids contamination of samples with dust or aerosol particles in the air. Soil samples were taken from different depths – 5, 20, and 30 cm. In total, about 20 soil samples were collected. The study provides an analysis of only 5 soil samples, as the examination of other samples is ongoing, and their results are not yet ready for inclusion in the analysis.

Soil samples were taken at various sections of the military training ground. Some samples were taken in the centre of the crater formed during the explosion of a 120 mm MP-120 mortar (manufactured by the Ukrainian Armor company) and on the periphery of this crater. In addition, other soil samples were collected in the centre of the crater formed by the explosion of an 82 mm mortar and on its periphery. Another soil sample was taken on the territory of the training ground outside the war zone. The soil samples were the same for all variants. Each sample was placed in a package that was clearly marked with a label indicating the place of sampling. The sampling sites of the objects under study are shown in Table 1.

Table 1. Soil samples selected for research

Sample number	Place of selection
Sample No. 1	Soil from the crater, centre (120-mm calibre mortar)
Sample No. 2	Soil from the crater, centre (82-mm calibre mortar)
Sample No. 3	Soil from the crater, periphery (120-mm calibre mortar)
Sample No. 4	Soil from the crater, centre (82-mmcalibre mortar)
Sample No. 5	Soil on the territory of the training ground outside of combat operations

Source: developed by the authors

The elemental composition examination of the soil (boron (B), copper (Cu), manganese (Mn), zinc (Zn), iron (Fe)) was conducted in the laboratory of the LLC “Ukravit Company” in the city of Cherkasy, using an inductively coupled plasma atomic emission spectrometer ICP 9800 Shimadzu (Japan), which has international accreditation DSTU EN ISO/IEC 17025:2019 (2019). All studies were conducted in accordance with the current regulatory documents, the responsibility for the accuracy of which is borne by the laboratory.

Soil and geochemical surveys were performed using the following methods: easily hydrolysed nitrogen (DSTU 7863:2015, 2015), pH of salt extract, mobile phosphorus compounds (P_2O_5) (DSTU 4115-2002, 2002), potassium exchange (DSTU 7861:2015, 2015), moving boron compounds (ISO 22036:2024, 2024), moving iron compounds (DSTU 4770.4:2007, 2007), moving manganese compounds (DSTU 4770.1:2007, 2007), moving copper compounds

(DSTU 4770.6:2007, 2007), mobile zinc compounds (DSTU 4770.4:2007, 2007).

The atomic emission analysis method is important for determining the heavy metal content in soil with quantitative accuracy and high sensitivity. Therefore, the analysis of the content of heavy metals in the soil was conducted by this method. Atomic emission spectrophotometry was performed from an acetate-ammonium buffer solution (ph=4.8).

The elemental composition of soils was also analysed using X-ray fluorescence. X-ray fluorescence spectra were obtained on the Rigaku EDXRF spectrometer (Japan) with an energy dispersion detector in the energy range from 2 to 10 keV. The spectra were recorded and processed using the ElvaX software. The dried soil was placed in special moulds and examined in the educational and scientific laboratory for physical and chemical research of materials at the Bohdan Khmelnytskyi Cherkasy National University. Such an integrated approach to the

collection and analysis of soil samples allows obtaining objective data on the state of soils at military training grounds, which is important for assessing the environmental situation and developing measures to improve it. Monitoring and analysis of such data is necessary to ensure environmental safety on the territory of military training grounds and ensure sustainable development.

RESULTS AND DISCUSSION

An important tool for assessing soil quality, detecting its contamination, examining agricultural opportunities, and checking the content of minerals necessary for plant growth and yield is soil analysis for the content of harmful substances and heavy metals. The X-ray fluorescence method of elemental analysis has shown high efficiency and reliability in conducting such inspections and is widely used in industry, agriculture, and scientific research. This method allows obtaining complete and reliable information about the composition of substances, regardless of their origin and aggregate state, for a minimum period of time.

The results of elemental analysis obtained using the X-ray fluorescence method were performed for all soil samples. However, the results of only one sample are presented as an illustration since the results of the analysis of other samples showed similarities with each other. As can be seen, elemental analysis showed substantial iron (Fe) content and the presence of elements such as silicon, potassium, calcium,

titanium, vanadium, manganese, and tungsten. In particular, titanium-based alloys with vanadium additives are used in aviation and rocket technology. Figure 1 shows the results of X-ray fluorescence of the soil of sample No. 2.

This method allows accurately determining the concentration of various chemical elements, including heavy metals, which can be potentially dangerous to the environment and human health. The atomic emission method is a fast and reliable way to determine the content of heavy metals in the soil, which allows detecting any contamination in time and taking the necessary measures for their further control and management. The obtained research results are shown in Table 2.

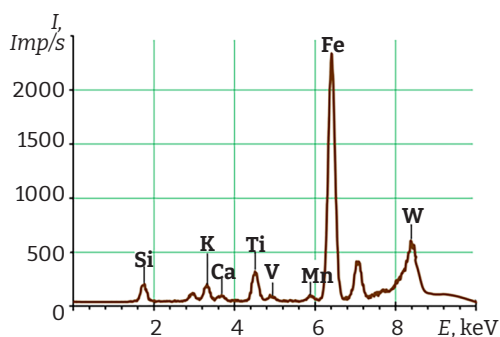


Figure 1. Soil X-ray fluorescence spectrum (sample No. 2)

Note: I , Imp/s – signal intensity, pulses per second; E , keV – the energy of characteristic radiation, kiloelectronvolts.

Source: compiled by the authors

Table 2. Heavy metal content in the soils of a military training ground

Metal content (mobile form)	Cu, mg/kg	PB, mg/kg	Zn, mg/kg	Mn, mg/kg	Fe, mg/kg
MPC, mg/kg	3.0	6.0	23.0	1500.0	Not normal
Sample No. 1	1.1	5.9	9.1	18.6	32
Sample No. 2	1.1	2.8	8.2	18.2	31
Sample No. 3	2.8	4.2	15	20.1	36
Sample No. 4	1.5	2.4	8.0	18.01	30
Sample No. 5	0.9	1.0	6.0	16.0	18

Note: MPC – maximum permissible concentration

Source: developed by the authors

Excess of the maximum permissible concentration in the examined soils was not recorded, which indicates a satisfactory condition of the soils according to certain parameters. However, it is worth paying attention

to the fact that the lead content in sample No. 1 was maximum and close to the maximum permissible concentration, which is the reason for caution and the need for further monitoring of this parameter.

The highest content of manganese in soils reached 20.1 mg/kg, respectively, 5 metres from the crater. The smallest amount – 16.0 mg/kg was identified on the territory of the training ground outside of combat operations. Manganese is a

heavy metal belonging to hazard class 3. The presence of manganese above the threshold level has a detrimental effect on the human body, which is manifested in the destruction of the central nervous system (Fig. 2)

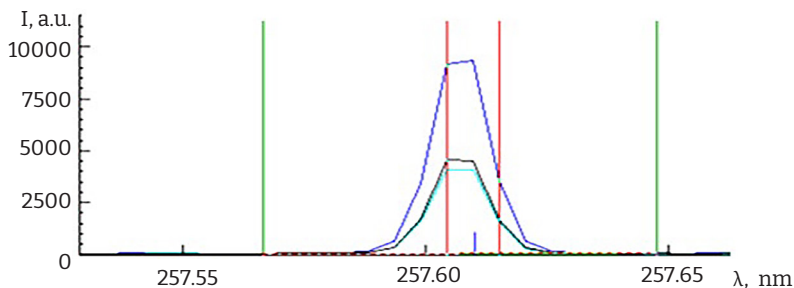


Figure 2. Emission spectrum of a sample in the determination of manganese (sample No. 2)

Note: I, a.u. – intensity of radiation, arbitrary units; λ , nm – wavelength, nanometers.

Source: compiled by the authors

This indicates that the manganese content in the soils varied depending on the sample collection location. The highest manganese content, which amounted to 20.1 mg/kg, was found in samples taken 5 metres away from the crater, which may indicate the influence of combat activities on the concentration of this metal in the soil. Conversely, the lowest manganese content, which amounted to 16.0 mg/kg, was found in the area of the training ground outside the combat zone, which may indicate a lesser impact of military-technogenic pressure on these areas. Exceeding the content of the determined metals poses a threat not only to the soil but also to humans. Dangerous substances can migrate from the soil into plants and from there into the bodies of people who consume these plants as food. Since the area on the training ground is rugged, with little vegetation and minimal migration of heavy metals into plants, the restoration of the soil cover is complicated because the transfer of heavy metals into vegetation is practically absent.

When analysing soils, it is important to remember one of the key indicators – pH. Analysing the soil pH is crucial because it allows determining the level of acidity or alkalinity of the environment. This indicator is of great significance for assessing soil fertility, as most plants can optimally develop within a certain pH range. For example, acidic soils can affect the availability of certain macro- and micronutrients to plants,

which can lead to nutrient deficiencies and, consequently, reduced yields. Conversely, overly alkaline soils can be unfavourable for most plants due to nutrient dissolution and may cause salt stress. Therefore, determining the soil pH helps identify potential problems and establish necessary measures to improve fertility and optimise conditions for plant growth and development. Conclusions about soil acidity or alkalinity can be made by determining the pH of the soil's water and salt extracts. This is also one of the indicators of soil fertility. Table 3 presents the results of soil sample studies based on the pH parameter and the mobile forms of some elements.

The soils in the areas of military training (samples No. 1-4) are slightly acidic (pH = 3.8-4.2), while the soil sample No. 5 is practically close to neutral (pH = 6.2). This can be explained by the fact that a large number of explosions and the dispersion of heavy metals occur during military training, which can lead to changes in the chemical composition of the soil and a decrease in its pH. The results showed that the soils in the military training areas have a significantly lower pH, which may be the result of the decomposition of explosive substances and other chemical reactions that occur during such events. On the other hand, soil sample No. 5, taken outside the areas of military activities, has an almost neutral pH value, which may indicate a lesser impact of military loads and pollutants on this area. If the

soil is too acidic, it hinders the achievement of high yields. Moreover, acidic soils enhance the migration of heavy metals, while alkaline soils limit the mobility of potentially toxic elements. In addition, plants cannot fully obtain nutrients from the soil because excessive acidity inhibits the activity of beneficial microorganisms that decompose various forms of organic residues, which in turn release available nutrients for plants. The best and most favourable indicator is considered to be pH close to neutral.

Important nutrients for plants that determine their health and development are nitrogen, phosphorus, potassium, boron, and sulfur. The presence of these elements in the soil is critical to providing plants with necessary nutrients. Therefore, this study carefully analysed the content of these nutrients in the soil. Nitrogen plays a key role in the formation of proteins and other vital organic compounds in plants. It is a component of amino acids, enzymes, and nucleic acids. Phosphorus is necessary for photosynthesis, energy transfer, and metabolism regulation. Potassium promotes plant growth and development, regulates water balance, and resistance to stress. Boron is necessary for the development of flowers and seeds, cell wall formation, and metabolism regulation. Sulfur is a component of amino acids, vitamins, and enzymes; it is important for protein synthesis and metabolism regulation. The analysis of these elements in the soil allowed determining how well the soil is

supplied with essential nutrients for plant growth and development. Such analysis helps identify the nutritional needs of plants and develop strategies to support their optimal health (Table 3). The availability of mobile forms of alkaline hydrolysable nitrogen and sulfur is very low, the mobile forms of phosphorus are at a medium level, and the exchangeable potassium is low (according to the classification of F.A. Yudin).

Boron does not occur in a free state in nature. It is present in soils in two forms: inorganic and organic. For normal development, microorganisms and plants use boron in its inorganic form and then convert it into an organic form. After they complete their life cycle and die, the organic form of boron oxidises and turns back into an inorganic form. In the soil, boron is found as the acid H_3BO_3 (at pH 5-9) or the anion $[B(OH)_4]^-$ (at pH >9.2). It enters the plant in the form of the boric acid anion BO_3^{3-} . Based on the degree of supply of water-soluble boron (in mg per 1 kg of soil), soils are divided into the following groups: I – very low <0.15 mg, II – low 0.15-0.33 mg, III – medium 0.33-0.50 mg, IV – high 0.50-0.70 mg, V – very high >0.70 mg (Esringü *et al.*, 2011). The content of mobile boron in the studied soil samples varies from 0.057 to 0.060 mg/kg (Table 3). The overall assessment of the condition of the studied samples in terms of mobile boron content is characterised as very low (>0.15 mg/kg), indicating a low potential for growing agricultural crops (Fig. 3).

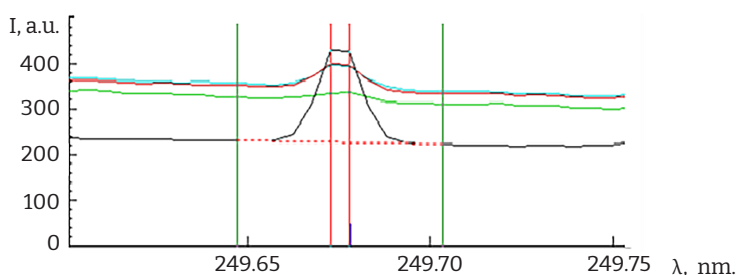


Figure 3. Emission spectrum of the sample in determining boron (sample No. 2).

Note: I, a.u. – intensity of radiation, arbitrary units; λ , nm – wavelength, nanometers.

Source: developed by the authors

Overall, according to estimates by experts from the Food and Agriculture Organization of the United Nations, boron deficiency is one of the major constraints on global crop production. Boron deficiency is considered the second

most important micronutrient for agricultural crops after zinc (Goldbach *et al.*, 2002). Military conflicts have a significant impact on soil characteristics, mainly due to the occurrence of certain physico-chemical disturbances and

contaminations. These consequences are especially dangerous for soils used in agriculture. They can have a serious impact on soil fertility and its ability to maintain high yields. Analysis of global experience shows that military actions can cause significant changes in the quality and structure of soils. Based on the analysis conducted by A. Berhe (2006) and D. Vidosavljević *et al.* (2013), the concentration of heavy metals in the soil significantly increased during the Croatian War. The levels of arsenic, mercury, and lead in areas where intense fighting occurred exceeded the national legislative standards. After the end of the Croatian War in 1995, about 23% of the country's territory, approximately 13,000 km², was contaminated with about 2 million mines. However, now only 3% of these contaminated areas remain mined, and they are planned to be cleared by 2026, which will be 30 years after the war ended. The area of mined territories in Ukraine exceeds that of three Croatias. The intensity of hostilities during the Russian invasion is much higher than in the Croatian War, especially in terms of the density of mined areas.

According to M. Sadiq *et al.* (1992), after the Persian Gulf War, there was an increase in the content of heavy metals in the soil. The highest concentrations were recorded for cadmium, cobalt, chromium, lead, nickel, titanium, vanadium, and tungsten. Exceeding the maximum allowable concentrations of heavy metals in soils occurred as a result of military conflicts in Bosnia and Herzegovina, Iran, Kuwait, the Northern Mariana Islands, and others (Broomandi *et al.*, 2017; Tomić *et al.*, 2018a; 2018b). L.V. Mishchenko (2010) investigated the impact of military activities on the ecological state of the environment. L.I. Odosiy *et al.* (2015) noted that even if there are less contaminated areas on military training grounds where direct hostilities do not occur, military-technogenic pressure still leaves a mark on the soil. Y. Kopytsia & T. Semenchenko (2022) claim that daily hostilities and unexploded ordnance negatively affect all ecosystems, but the soil suffers the most. Each explosion destroys the soil layer, damaging the ecological and agricultural potential of the country. It is evident that the occupiers are trying to create unfavourable living conditions for future generations. The war waged by Rus-

sia is a challenge not only for Ukraine but for the entire world. Hostilities have destroyed forests, soils, and nature reserves, and more than 200,000 hectares of land are contaminated with shells, mines, and ammunition fragments.

Previous attempts to assess the condition of military training grounds and adjacent areas have already been conducted by N. Lisova (2017), P. Broomandi *et al.* (2020), Yu. Zaitsev *et al.* (2022) did not consider the load that occurs due to the explosion of artillery shells of different types with varying gunpowder charge masses. A clear analysis of the chemical composition of soils and their changes under the influence of military-technogenic loads underscores the importance of examining chemistry in agricultural higher education institutions (Pozharytskyi & Shaforost, 2022). Understanding the chemical processes occurring in the soil is crucial for ensuring the sustainability and fertility of soils, which are key to the agricultural sector. M.J. Lawrence *et al.* (2015) noted that military activities predominantly have a negative impact on the structure and functioning of ecosystems, manifesting in habitat destruction, environmental pollution, and decreased biodiversity. However, in some cases, military activity can have a positive effect, such as creating exclusion zones that promote population recovery or introducing new technologies that aid in conservation research.

All of this indicates a significant interest in the problem of chemical military-technogenic load on the soils of military training grounds. However, many aspects of this problem still require further exploration. For instance, it is important to conduct more detailed studies on the specific impact of different types of military activities on the composition and quality of soils and to develop effective strategies for rehabilitation and restoration of ecological sustainability in such areas. Thus, further studies in this area are of great importance for the preservation of the environment.

CONCLUSIONS

Soil analysis for the content of harmful substances and heavy metals is an integral part of assessing soil quality and its agricultural potential. The X-ray fluorescence method of elemental analysis has proven to be an effective

and reliable tool for such assessments, providing complete and accurate information about the composition of substances in the soil. The results showed a high iron content, which may be related to military activities occurring at the training ground, such as the use of explosions, artillery shelling, and other military measures, where iron may be used in various forms or materials, affecting its concentration in the soil. The atomic emission method of analysing heavy metals also allowed for precise determination of their concentration with high sensitivity and accuracy. It should be noted that although there were no recorded exceedances of maximum allowable concentrations (MAC) in the studied soils, the maximum lead content approached the MAC, requiring further monitoring and control of this parameter. Manganese, as a heavy metal, significantly impacts the human body, so its concentration in the soil is important to consider.

The analysis showed a difference in manganese content depending on the sampling location, indicating variability in its concentration in the combat zone compared to areas outside of it. Chemical studies of the soils at the military training ground in the Cherkasy region to assess the environmental situation have led to several important conclusions. The results of the tests indicate a slight technogenic load at the sites of military exercises. The detected contamination of the examined samples is insubstantial, which indicates that the impact of military activities on the soil condition is limited. The mobile content of heavy metals, which is an ecological-

geochemical criterion for determining zones of ecological risk, also confirms this conclusion. All soil samples showed a significant decrease in indicators responsible for soil fertility, such as nitrogen, phosphorus, potassium, sulfur, and trace elements. This may be a consequence of the use of explosives at the training ground, affecting soil biological activity and fertility.

In this context, it is important to pay special attention to baseline soil quality indicators and consider the amount of pollutants from various sources, including the volumes of explosives used. The study concluded that the technogenic load on the soils after military training is minimal. However, despite the detected minor contamination, continuous monitoring of soil quality remains critically important to ensure environmental safety and sustainable use of natural resources. Research on the chemical military-technogenic load on military training ground soils opens up broad possibilities for further studies in this area. In the future, it is necessary to investigate more deeply the impact of such loads on human health and the environment. It is also important to examine the effect of chemical pollution on vegetation and biodiversity, as this will help to understand the consequences for ecosystems better and identify possible ways to restore natural habitats.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

- [1] Barker, A.J., Clausen, J.L., Douglas, T.A., Bednar, A.J., Griggs, C.S., & Martin, W.A. (2021). Environmental impact of metals resulting from military training activities: A review. *Chemosphere*, 265, article number 129110. doi: [10.1016/j.chemosphere.2020.129110](https://doi.org/10.1016/j.chemosphere.2020.129110).
- [2] Berhe, A. (2006). The contribution of landmines to land degradation. *Land Degradation and Development*, 18(1), 1-15. doi: [10.1002/ldr.754](https://doi.org/10.1002/ldr.754).
- [3] Broomandi, P., Dabir, B., Bonakdarpour, B., & Rashidi, Y. (2017). Identification of dust storm origin in the southwest of Iran. *Journal of Environmental Health Science and Engineering*, 15, article number 16. doi: [10.1186/s40201-017-0280-4](https://doi.org/10.1186/s40201-017-0280-4).
- [4] Broomandi, P., Guney, M., Kim, J.R. & Karaca, F. (2020). Soil contamination in areas impacted by military activities: A critical review. *Sustainability*, 12(21), article number 9002. doi: [10.3390/su12219002](https://doi.org/10.3390/su12219002).
- [5] DSTU 4115-2002. (2002). *Soils. Determination of mobile phosphorus and potassium compounds by the modified Chirikov method*. Retrieved from <http://surl.li/ukhzu>.

- [6] DSTU 4770.1:2007. (2007). *Soil quality. Determination of the content of mobile manganese compounds in soil in a buffered ammonium acetate extract with pH 4.8 by atomic absorption spectrophotometry*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=58849.
- [7] DSTU 4770.4:2007. (2007). *Soil quality. Determination of the content of mobile iron compounds in soil in a buffered ammonium acetate extract with pH 4.8 by atomic absorption spectrophotometry*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=58854https://online.budstandart.com/ua/catalog/doc-page?id_doc=58854.
- [8] DSTU 4770.6:2007. (2007). *Soil quality. Determination of the content of mobile copper compounds in soil in a buffered ammonium acetate extract with pH 4.8 by atomic absorption spectrophotometry*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=58930.
- [9] DSTU 7861:2015. (2015). *Soil quality. Determination of exchangeable calcium, magnesium, sodium and potassium in soil by Schollenberger as modified by the Sokolovsky National Research Centre of IGA*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=62743.
- [10] DSTU 7863:2015. (2015). *Soil quality. Determination of easily hydrolysable nitrogen by the Cornfield method*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=62745.
- [11] DSTU EN ISO/IEC 17025:2019. (2019). *General requirements for the competence of testing and calibration laboratories*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=88724.
- [12] Esringü, A., Turan, M., & Gunes, A. (2011). Boron application improves the yield and chemical composition of strawberries. *Acta Agriculturae Scandinavica. Section B – Soil & Plant Science*, 61(3), 245-252. doi: 10.1080/09064711003776867.
- [13] Goldbach, H.E., et al. (2002). Rapid responses of plants to boron deprivation. In H.E. Goldbach, P.H. Brown, B. Rerkasem, M. Thellier, M.A. Wimmer & R.W. Bell (Eds.), *Boron in plant and animal nutrition* (pp. 167-180). Boston: Springer. doi: 10.1007/978-1-4615-0607-2_15.
- [14] ISO 22036:2024. (2024). *Environmental solid matrices – determination of elements using inductively coupled plasma optical emission spectrometry (ICP-OES)*. Retrieved from <https://icontec.isolutions.iso.org/ru/standard/82632.html>.
- [15] Kopytsia, Y., & Semenchenko, T. (2022). Environmental consequences of Russian aggression invasion of Ukraine. *Economics. Finances. Law*, 6(1), 5-10. doi: 10.37634/efp.2022.6(1).1.
- [16] Krylova-Grek, Y.M. (2022). Mass media as a factor influencing the concepts semantic field. *Signo*, 47(88), 65-72. doi: 10.17058/signo.v47i88.17383.
- [17] Lawrence, M.J., Stemberger, H.L., Zolderdo, A.J., Struthers, D.P., & Cooke, S.J. (2015). The effects of modern war and military activities on biodiversity and the environment. *Environmental Research*, 23(4), 443-460. doi: 10.1139/er-2015-0039.
- [18] Lisova, N. (2017). [Impact of military actions in Ukraine on the ecological state territory](#). *Scientific Issues of Ternopil Volodymyr Hnatiuk National Pedagogical University. Series: Geography*, 43(2), 165-173.
- [19] McNutt, M., & Hildebrand, J. (2022). Scientists in the line of fire. *Science*, 375(6585), article number 1071. doi: 10.1126/science.abp8817.
- [20] Mishchenko, L.V. (2010). [Environmental consequences of military activity and possible ways to overcome them](#). *Scientific Bulletin of NGDU*, 1, 96-100.
- [21] Odosiy, L.I., Stadnichuk, O.M., Sviderok, S.M., Nadala, O.S., & Gychko, O.S. (2015). The influence of the man-made load of military activity on the state of the soil and water environment. *Military and Technical Collection*, 12, 91-96. doi: 10.33577/2312-4458.12.2015.91-96.

- [22] Pozharytskyi, O., & Shaforost, Yu. (2022). Peculiarities of remote teaching of chemical disciplines in agricultural institutions of higher education. *Bulletin of Science and Education*, 6(6), 185-193. [doi: 10.52058/2786-6165-2022-6\(6\)-185-193](https://doi.org/10.52058/2786-6165-2022-6(6)-185-193).
- [23] Sadiq, M., Althagafi, K.M., & Mian, A.A. (1992). Preliminary evaluation of metal contamination of soils from the gulf war activities. *Bulletin of Environmental Contamination and Toxicology*, 49, 633-639. [doi: 10.1007/bf00200774](https://doi.org/10.1007/bf00200774).
- [24] Shaforost, Yu.A., Galagan, R.L., Korol, Ya.D., & Lut, O.A. (2022). Basics of waste-free processing of sludge waste from "Cherkasy Khimvolokno" chemical plant. *Voprosy Khimiii Khimicheskoi Tekhnologii*, 6, 108-114. [doi: 10.32434/0321-4095-2022-145-6-108-114](https://doi.org/10.32434/0321-4095-2022-145-6-108-114).
- [25] Shukla, S., Mbingwa, G., Khanna, S., Dalal, J., Sankhyan, D., Malik, A., & Badhwar, N. (2023). Environment and health hazards due to military metal pollution: A review. *Environmental Nanotechnology, Monitoring & Management*, 20, article number 100857. [doi: 10.1016/j.enmm.2023.100857](https://doi.org/10.1016/j.enmm.2023.100857).
- [26] Skalny, A.V., Aschner, M., Bobrovnitsky, I.P., Chen, P., Tsatsakis, A., Paoliello, M.M., Djordevic, A.B., & Tinkov, A.A. (2021). Environmental and health hazards of military metal pollution. *Environmental Research*, 201, article number 111568. [doi: 10.1016/j.envres.2021.111568](https://doi.org/10.1016/j.envres.2021.111568).
- [27] Stadler, T., Temesi, Á., & Lakner, Z. (2022). Soil chemical pollution and military actions: A bibliometric analysis. *Sustainability*, 14(12), article number 7138. [doi: 10.3390/su14127138](https://doi.org/10.3390/su14127138).
- [28] Tomić, N.T., Smiljanić, S., Jovic, M., Gligorić, M., Povrenović, D., & Došić, A. (2018a). Examining the effects of the destroying ammunition, mines, and explosive devices on the presence of heavy metals in soil of open detonation pit: Part 1 – pseudo-total concentration. *Water Air and Soil Pollution*, 229, article number 301. [doi: 10.1007/s11270-018-3957-0](https://doi.org/10.1007/s11270-018-3957-0).
- [29] Tomić, N.T., Smiljanić, S., Jovic, M., Gligorić, M., Povrenović, D., & Došić, A. (2018b). Examining the effects of the destroying ammunition, mines, and explosive devices on the presence of heavy metals in soil of open detonation pit; part 2: Determination of heavy metal fractions. *Water, Air, and Soil Pollution*, 229, article number 303. [doi: 10.1007/s11270-018-3950-7](https://doi.org/10.1007/s11270-018-3950-7).
- [30] Vidosavljević, D., Puntarić, D., Gvozdić, V., Jergović, M., Miškulin, M., Puntarić, I., Puntarić, E., & Šijanović, S. (2013). Soil contamination is a possible long-term consequence of the war in Croatia. *Acta Agriculturae Scandinavica, Section B – Soil & Plant Science*, 63(4), 322-329. [doi: 10.1080/09064710.2013.777093](https://doi.org/10.1080/09064710.2013.777093).
- [31] Yang, S., Chen, Z., Cheng, Y., Liu, T., Yin, L., Pu, Y., & Liang, G. (2021). Environmental toxicology wars: Organ-on-a-chip for assessing the toxicity of environmental pollutants. *Environmental Pollution*, 268(B), article number 115861. [doi: 10.1016/j.envpol.2020.115861](https://doi.org/10.1016/j.envpol.2020.115861).
- [32] Zaitsev, Yu.O., Hryshchenko, O.M., Romanova, S.A., & Zaitseva, I.O. (2022). The influence of hostilities on the content of gross forms of heavy metals in the soils of the Sumy and Okhtyr districts of the Sumy region. *Agroecological Journal*, 3, 136-149. [doi: 10.33730/2077-4893.3.2022.266419](https://doi.org/10.33730/2077-4893.3.2022.266419).

Юлія Шафорост

Кандидат хімічних наук, доцент

Черкаський національний університет імені Богдана Хмельницького

18031, б-р Шевченка, 81, м. Черкаси, Україна

<https://orcid.org/0000-0002-0002-2803>

Олег Погребняк

Кандидат хімічних наук, доцент

Черкаський національний університет імені Богдана Хмельницького

18031, б-р Шевченка, 81, м. Черкаси, Україна

<https://orcid.org/0009-0000-2289-0487>

Олена Лут

Кандидат хімічних наук, доцент

Черкаський національний університет імені Богдана Хмельницького

18031, б-р Шевченка, 81, м. Черкаси, Україна

<https://orcid.org/0000-0002-0288-4255>

Валентина Литвин

Кандидат хімічних наук, доцент

Черкаський національний університет імені Богдана Хмельницького

18031, б-р Шевченка, 81, м. Черкаси, Україна

<https://orcid.org/0000-0003-1236-6344>

Олександр Шевченко

Кандидат хімічних наук, доцент

Черкаський національний університет імені Богдана Хмельницького

18031, б-р Шевченка, 81, м. Черкаси, Україна

<https://orcid.org/0009-0007-5769-1884>

Хімічне воєнно-техногенне навантаження на ґрунти військових полігонів

Анотація. Дослідження про воєнно-техногенне навантаження на природне середовище внаслідок міжнародних конфліктів є актуальним, оскільки воєнні дії спричиняють катастрофічні наслідки для екології та природних ресурсів, що може призвести до незворотних порушень у екосистемах. Стаття присвячена дослідженню впливу військово-техногенного навантаження на ґрунти військових полігонів. У роботі розглянуто методи відбору проб ґрунту, їх аналіз на вміст важких металів та інших хімічних сполук, а також визначено вплив цього навантаження на екосистему та можливі наслідки для здоров'я людини. Проаналізовано вплив військової діяльності на якість ґрунтів військових полігонів, зокрема в Черкаській області. Дослідження включає визначення методом рентгенівської флуоресценції та атомно-емісійним методом вмісту різних елементів у ґрунті. Результати показали значний вміст заліза, що може бути пов'язано з використанням вибухових речовин у військових навчаннях. Зазначено, що попри те, що перевищення норм гранично допустимої концентрації вмісту важких металів у досліджуваних ґрунтах не було зафіксовано, максимальний вміст свинцю наближався до гранично допустимої концентрації, що вимагає подальшого спостереження та контролю за цим параметром. Визначення рН показала слабо-кислий стан ґрунтів в місцях

проведення бойових навчань, що може впливати на родючість та ріст рослин. Досліджено вміст азоту, фосфору, калію та бору, результати показали недостатність цих поживних речовин для нормального розвитку рослин. Встановлено, що пошкодження ґрунтів внаслідок воєнних дій може мати тривалий негативний вплив та становити загрозу для жителів та територій. Результати аналізів свідчать про незначне техногенне навантаження на місцях проведення військових навчань. Виявлене забруднення досліджуваних зразків є незначним, що свідчить про те, що вплив військової діяльності на стан ґрунтів є обмеженим. Результати дослідження допоможуть зрозуміти можливі ризики для здоров'я людей, які проживають поблизу військових полігонів, та вжити відповідних заходів для захисту їх здоров'я

Ключові слова: хімічне забруднення; важкі метали; моніторинг забруднення; військові навчання; екологічні наслідки